# SEMICONDUCTOR CIRCUITS FOR HYBRID COLOR TELEVISION

by Derek Bray

## INTRODUCTION

Considerable work has been done by Fairchild Semiconductor on the feasibility and design of practical and economical circuits for large-screen color television receivers. Some of the early work in this area has already been published.[1,2] Recent design effort has resulted in a more economical design with better performance. This has been achieved by simplifying circuit design and by using integrated circuits where they offer more reliable performance and circuit simplicity.

A standard 19-inch tube receiver was modified to evaluate the design changes. In the modified receiver, the following circuits use semiconductors:

1. UHF Tuner
2. VHF Tuner
3. Video IF Amplifier
4. Sound IF Amplifier
5. Audio Amplifier
6. Video Amplifier
7. AGC, Sync and Noise Inverter Circuits
8. Chroma Amplifier
9. Color Oscillator and Tint Control
10. ACC and Color Killer
11. Color Demodulator and Output Amplifiers.

The UHF and VHF tuners are standard production items and are readily available from tuner manufacturers. The horizontal oscillator, horizontal output, vertical oscillator, vertical output, high voltage, and convergence circuits were left unchanged using standard television tube circuits. This approach minimizes the interface problem between the solid-state and TV tube circuits and simplifies the conversion.

1. See list of references at end of the bulletin.

All semiconductor circuits, with the exception of the tuners, were designed by Fairchild Consumer Applications Group. These circuits will be described in more detail in the following sections. A block diagram of the complete receiver is shown in Fig. 1; the semiconductor circuits are given in Fig. 2. IF transformer data and color processing transformer data are given in the Appendix.

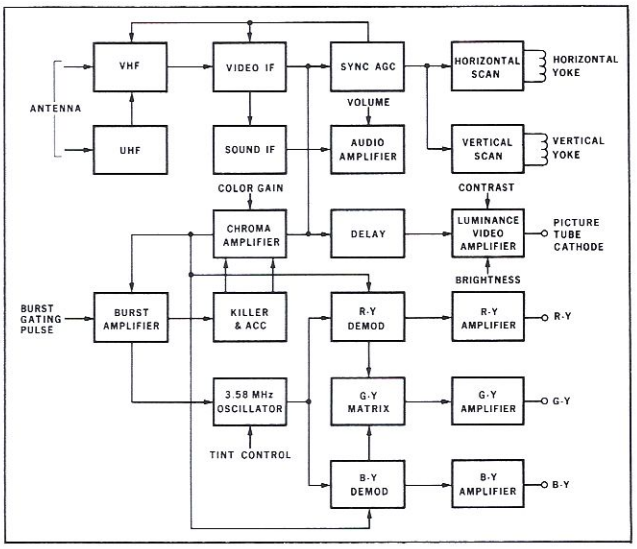


Fig. 1. Color TV block diagram.

## IF AMPLIFIER

The IF amplifier is a three-stage amplifier with the first stage, $Q_1$, forward AGC controlled. The interstage coupling between the first two stages has a low Q circuit tuned to 43.75 MHz. The low Q ensures a minimum varia-

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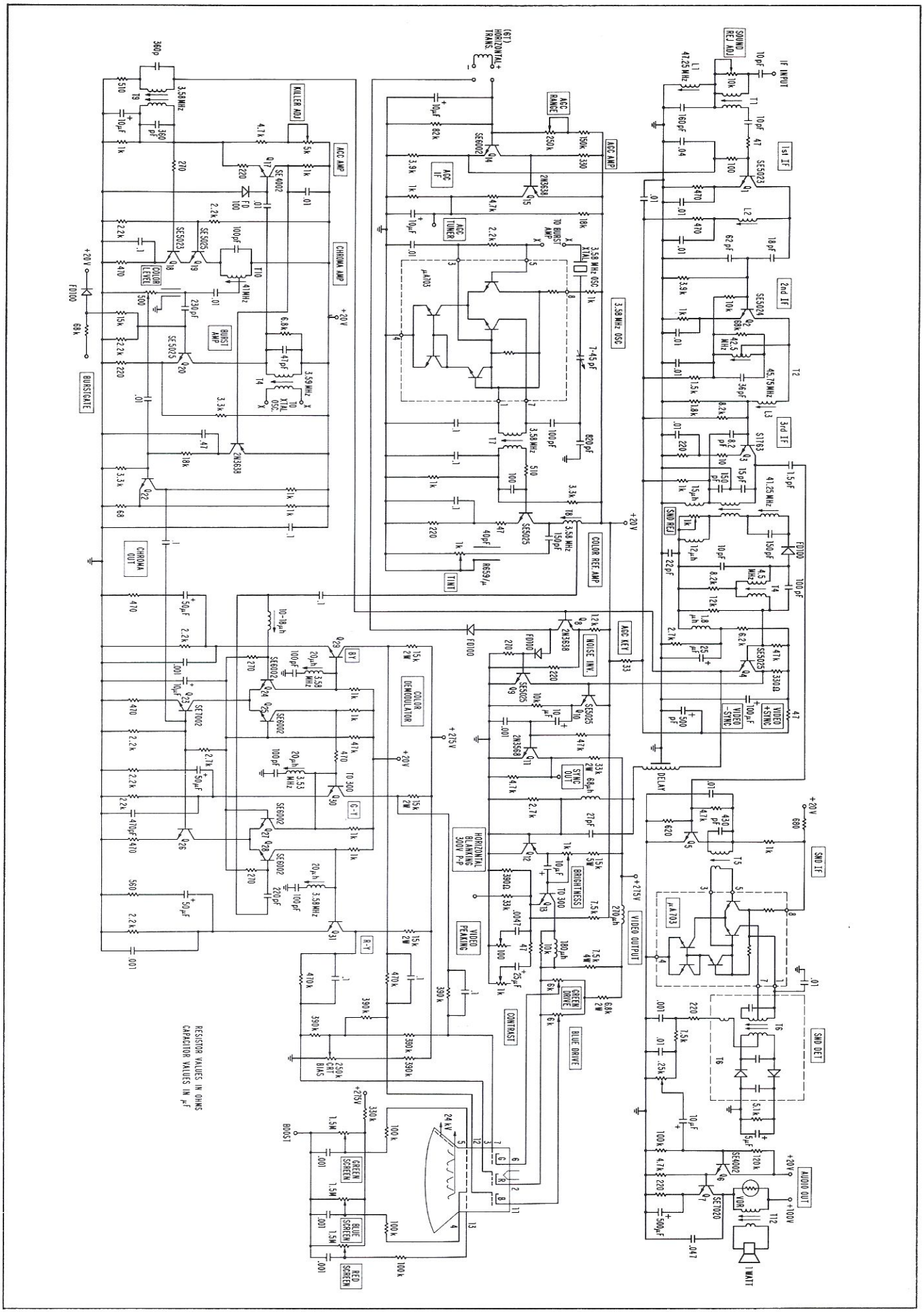


**Fig. 2. Color TV receiver schematic.**

tion of the overall IF response when the first stage is forward AGC controlled. The bifilar T trap at the input is tuned to adjacent channel sound and provides at least 60-db rejection at 47.25 MHz. The second stage, $Q_2$, is fixed gain with a two-pole coupling network between the second and third stages. These poles have Q's of 40 at 42.5 MHz and 26 at 45.75 MHz, respectively, and provide much of the overall band-shaping required to obtain the desired response. High Q's can be used in this interstage since neither the second nor third IF stages are AGC controlled, and hence, no pole shifting problems will occur. Both the first and second stages use low capacity devices, SE5023 and SE5024, which allow an unneutralized design to be used and still maintain adequate stability margins for the desired gain. These devices have been the subject of a paper presented at the National Electronics Conference in Chicago, October 1965,[3] and are now readily available from Fairchild Semiconductor.

The third IF output stage, $Q_3$, uses a new transistor which has been specifically designed for this application.[4] The output transformer and detector circuits contain the desired sound trapping at 41.25 MHz before detection and 4.5 MHz after detection. The sound detector is taken directly from the collector of the output stage prior to the sound trapping on the transformer secondary. The output stage is biased at 18 volts and 15 milliamps in order to obtain the desired linearity of output video.

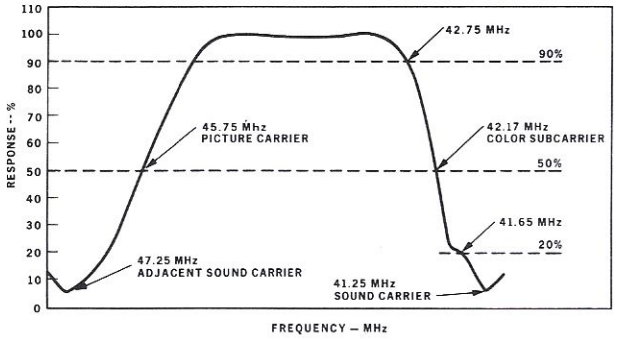


Fig. 3. Typical video IF response.

The overall IF response in Fig. 3 shows the co-channel and adjacent channel sound traps, picture carrier frequency (45.75 MHz) and the color subcarrier and bandpass limit frequencies (42.75, 42.17, and 41.65 MHz) The chroma bandpass is detected on the slope of the IF response so that the co-channel sound trap can maintain the desired 60-db rejection without introducing undesired phase shift in the chroma bandpass. Overall voltage gain is 75 decibels and power gain 50 decibels (45 MHz input level to detected video output level). Maximum undistorted video output is approximately 6 volts peak-to-peak and the maximum AGC range is 60 decibels.

## SOUND IF

The 1.5-pf takeoff capacitor at the collector of the third video IF stage, $Q_3$, feeds into a power detector, $Q_4$, and the 4.5-MHz component is filtered and further amplified in a $\mu$A703 integrated circuit. A ratio detector follows the $\mu$A703 to provide some AM rejection for small signals. For large signals, the $\mu$A703 operates as a current-limited amplifier providing excellent limiting properties. This circuit is described in more detail in Application Bulletin No. 146.[5]

## AUDIO AMPLIFIER

The audio amplifier consists of two stages: $Q_6$ is an emitter follower buffer stage to provide a high input impedance, and $Q_7$ is a 1-watt class-A output stage using a 300-volt transistor, SE7020, specifically designed for this application.

Less than 10 percent distortion at 1 watt can be achieved with an input signal of less than 200-mV RMS. The SE7020 is biased at 30 milliamps and 100 volts for optimum performance. High frequency roll off is provided by the 0.047-$\mu$f capacitor from collector-to-ground, and protection against high-voltage transients is provided by the Voltage Dependent Resistor (VDR) across the primary of the output transformer. The transformer ratio should be chosen to reflect a 3K impedance load to the primary.

The 1-watt output capability is considered adequate for a table model receiver. For console models with larger screen size, 2 watts would be desirable.

## LUMINANCE AMPLIFIER

The luminance amplifier consists of three stages. An emitter follower input stage, $Q_4$, provides a low-capacity high-impedance load to the IF video detector. The video signal at the emitter of $Q_4$ is 3 volts peak-to-peak and is dc-coupled through the delay line to the PNP emitter follower, $Q_{12}$. The $Q_{12}$ performs a dual function by presenting a high-impedance load to the delay line and a low-impedance drive to the video output stage, $Q_{13}$. This ensures that the delay line can be accurately terminated and will also minimize Miller capacity high-frequency roll-off in the output stage.

Brightness control is provided as a dc shift-of-operating point in the output stage, $Q_{13}$, by controlling the output base bias voltage. Contrast control and video-peaking controls are provided in the emitter circuit of $Q_{13}$. Horizontal blanking is also inserted at the emitter of $Q_{13}$. Conventional inductive peaking circuits, and blue and green drive controls, are used to couple the output stage to the picture tube cathodes.

The output video, $Q_{13}$, is a developmental type TO300, which is very similar to the SE7020 used in the audio output

stage. The overall video amplifier has an output capability of 200 volts peak-to-peak with a video bandwidth of 3 MHz. Contrast range is approximately 5:1

Typical T0300 device parameters are:

| | |
|---|---|
| $LV_{CEO}$ | > 300 volts |
| $h_{FE}$ | > 30 |
| ft | = 50 MHz typical |
| $C_{ob}$ | = 10 pf typical at $I_e = 0$ $V_{CB} = 50$ volts |
| j-c | = 6° C/Watt |

## AGC NOISE INVERTER AND SYNC SEPARATOR

$Q_8$ is the gated AGC stage. The voltage divider in the emitter of $Q_8$ determines the reference level to which the sync pulse tips on the video signal are referred. This voltage, together with the bias voltage applied to the video detector circuit on the IF, determines the video output amplitude which is typically 3 volts peak-to-peak. Gated AGC is provided by the gating pulse from a winding on the horizontal flyback transformer applied to the collector of $Q_8$ through a blocking diode.

The AGC control voltage is generated at the base of $Q_{14}$ across the base-decoupling capacitor. Provision is made for setting up maximum gain on the IF with no input signal.

Delayed AGC for the tuner is obtained by $Q_{15}$. When the current on $Q_{14}$ exceeds 2 milliamps, $Q_{15}$ turns on and provides a positive-going AGC for the tuner. The change in tuner AGC voltage at this point is much greater than the IF AGC voltage change. This circuit thus enables the following AGC action to take place.

With very small signals, the IF AGC controls the gain, allowing the signal-to-noise ratio in the tuner to improve. After 20 to 30 db of IF AGC, it is necessary to AGC the tuner and thus reduce cross-modulation problems in the mixer stage. This is achieved by using the turn-on-threshold of $Q_{15}$ to give the delay and the additional gain of $Q_{15}$ to ensure rapid tuner AGC. After allowing the tuner to AGC by 40 to 50 db, $Q_{15}$ saturates the AGC action and is transferred back to the IF, giving an overall AGC range of approximately 100 decibels. A plot of IF and tuner AGC voltages versus signal amplitude is shown in Fig. 4.

An inverted video signal for sync generation is derived from the collector of $Q_4$. An emitter follower buffer stage, $Q_{10}$, provides adequate drive to the conventional sync separator stage, $Q_{11}$. The $Q_{11}$ conducts only during sync periods and provides a 25-volt negative-going sync pulse at its collector. The 25-volt requirement is needed for operation of the horizontal and vertical tube circuits.

Spurious generation of sync pulses by noise is eliminated by use of a noise inverter stage, $Q_9$. During normal scanning periods, $Q_8$ acts as an amplifier for any signals

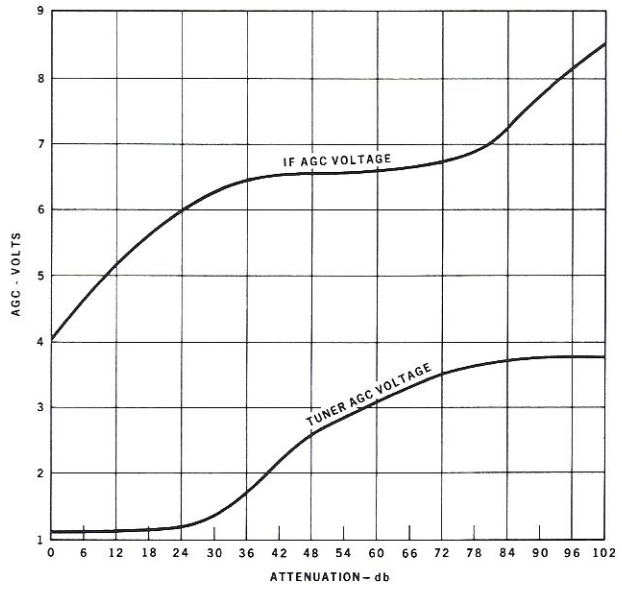


Fig. 4. AGC response curves.

more negative than sync pulses. If such a noise pulse exists, $Q_9$ is driven into conduction, pulls the base of $Q_{11}$ negative, and cancels out the positive noise pulse on the inverted video signal.

## CHROMA AMPLIFIER, ACC, COLOR KILLER, AND BURST AMPLIFIER

The chroma amplifier has to provide a response, which will compensate for the IF response in the chroma bandpass region. An idealized response to accomplish this is shown

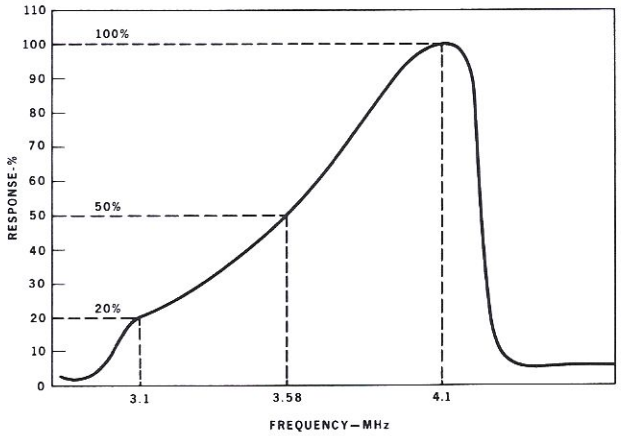


Fig. 5. Typical chroma response.

in Fig. 5. Other facilities which have to be provided are: (1) Automatic color control (ACC) to ensure that the correct color amplitude is always maintained: (2) Color killer control to ensure that, for monochrome operation, the chroma amplifier is cut off and cannot introduce additional noise.

The chroma amplifier response is obtained by a combination of a double-tuned transformer in the base of $Q_{18}$, followed by a single-tuned parallel resonant circuit in the collector of $Q_{19}$, with a pole at 4.1 MHz. Automatic color control is achieved by forward AGC on the first stage. $Q_{18}$ and $Q_{19}$ are cascode-connected to reduce output impedance variation and pole shifting for the 4.1-MHz circuit. The output of $Q_{19}$ is coupled through the color gain control to the base of $Q_{22}$, which acts as a video amplifier. Thus, $Q_{22}$ provides a gain of 10 for the chroma signal and an output capability of 10 volts peak-to-peak.

Burst amplification is achieved in $Q_{20}$, which conducts only during horizontal flyback periods. A gating pulse is derived from the horizontal flyback pulse by the diode clipping circuit. This clipping is necessary to ensure adequate burst gating for all settings of the horizontal hold control.

The burst amplitude at the collector of $Q_{20}$ is peak detected by the shunt diode detector circuit. The dc voltage produced is used to provide both ACC and killer control. $Q_{17}$ acts as an emitter follower for ACC action and provides an ACC control voltage at the emitter. Pre-bias on the emitter of $Q_{17}$ sets the maximum gain on $Q_{18}$ for no-burst signal conditions. As soon as the burst amplitude exceeds the threshold voltage, $Q_{17}$ conducts. The base-emitter voltage of $Q_{21}$ provides a threshold which controls the color killer operation.

When $Q_{17}$ conducts heavily, $Q_{21}$ is turned on and saturates, thus providing normal bias conditions for the chroma amplifier stage, $Q_{22}$. If there is no burst signal, $Q_{17}$ is cut off, and $Q_{22}$ base returns to ground potential. The pre-bias on the emitter of $Q_{22}$ thus ensures that $Q_{22}$ is cut off and reverse biased.

## COLOR OSCILLATOR AND TINT CONTROL

The color oscillator has been designed around the use of the $\mu$A703 integrated circuit and is used in an injection locked mode of operation. The basic oscillator circuit has been described in detail in Fairchild APP No. 145[6] where details of temperature and voltage stability are given.

The $\mu$A703 integrated circuit is basically an emitter-coupled circuit with a current source in the emitters. Other internal components provide biasing. The oscillator employs positive feedback from the output collector to the input base and uses the crystal in a series resonant mode in the feedback path. Injection-locked operation is achieved by coupling the amplified burst from the secondary of the burst amplifier transformer, in series with the crystal.

The $\mu$A703 provides current limiting in this mode of operation. A suitable choice of load resistor (less than 3 Kilohms) ensures that saturation cannot occur. This is a considerable improvement over a descrete transistor circuit previously used[1, 2] and presents both improved performance and a more economical circuit.

The injection-locked principle has been described in detail for a tube circuit[7] and relies in principle on the fact that the tuned circuit in series with the crystal acts as a variable reactance, the sign of which depends on the phase relationship between the injected burst and the oscillator phases. With this type of circuit, it is possible to obtain satisfactory phase stability with less than a 20-degree phase shift for a 100-Hz change in burst frequency.

The output of the oscillator is the transformer coupled to the tint amplifier stage, $Q_{16}$. Tint control is provided by a standard circuit utilizing a coaxial cable as a variable capacity. A tint range of approximately 90 degrees has been obtained from this circuit. An output voltage of 6 volts peak-to-peak is available as a reference voltage for the color demodulator.

## COLOR DEMODULATOR

Demodulation is achieved by using a differential amplifier in a switching mode (very similar to the operation of the $\mu$A703 under limiting conditions). One such demodulator consists of $Q_{23}$, $Q_{24}$, and $Q_{25}$. The chroma signal applied to the base of $Q_{23}$ is converted to a current source feeding into the emitters of $Q_{24}$ and $Q_{25}$. The 3.58-MHz reference signal from the tint circuit provides a switching action between $Q_{24}$ and $Q_{25}$ so that each conducts for 180 degrees. By choosing the desired phasing between the chroma signal and the reference signal, any desired demodulation angle can be obtained. In this case, the desired phase is chosen along the B-Y axis and the signal generated across the 1-K load resistor in the collector of $Q_{24}$ is the demodulated B-Y component. The series resonant trap to ground removes the 3.58-MHz components present in the signal at this stage.

The R-Y signal is similarly demodulated by providing a 90-degree phase shift between the B-Y and R-Y reference signals. This is achieved by having a 45-degree lag in the B-Y channel and a 45-degree lead in the R-Y channel. $Q_{26}$, $Q_{27}$, and $Q_{28}$ accomplished the demodulation for the R-Y channel. G-Y signals are obtained by matrixing -(B-Y) and -(R-Y) from the collectors of $Q_{25}$ and $Q_{27}$.

High-level color-difference signals capable of driving any large screen color tube are provided by the three-output amplifier stages, $Q_{29}$, $Q_{30}$, and $Q_{31}$. The gains of each stage are controlled by the value of the emitter resistors. To improve the chroma transient responses, a certain amount of peaking is introduced by bypass capacitors in the emitter circuits. Each output stage has a capability of 200 volts peak-to-peak to the grid of the picture tube.

A chroma signal of 6 volts peak-to-peak is required to provide full output capability for the demodulated signal.

The reference voltage has to be greater than 3 volts peak-to-peak to ensure 180-degree sampling of the chroma signal and correct demodulation.

## POWER SUPPLIES

A 270-volt high-voltage line was used for all tube circuits and viedo output stages. The low-level transistor circuits are operated from an unregulated 20-volt power supply. Line voltage variations of ± 15 percent can be tolerated with the possible exception of readjustment of the vertical hold control.

Power Requirements for the Receiver:

| | | | |
|---|---|---|---|
| Low-voltage transistor circuits | 20 V | 300 mA | 6 W |
| High-voltage transistor circuits | 270 V | 120 mA | 33 W |
| Tube heaters | 6.3 V | 3.2 A | 20 W |
| All tube circuits, high voltage, convergence, etc. | 270 V | 300 mA | 81 W |
| Transformer & Power-Supply losses | | | 30 W |
| | Total Power | | 170 W |

This represents a power saving of 150 watts as compared to a conventional all-tube receiver which has a power dissipation of 320 watts.

These figures indicate that an all transistor receiver could possibly reduce the power requirements by an additional 30 watts resulting in an overall dissipation of 140 watts.

## OVERALL PERFORMANCE

The performance provides considerable improvement over that of previous hybrid receivers.[1,2] The performance is considered entirely satisfactory, with the exception of some internal interference feeding back to the antenna. These interference patterns are noticeable on close inspection but are not objectionable to normal viewing. Suitable screening of circuits and components could remove this problem. A list of devices used in this receiver is given in Table I.

**TABLE I.**
**Parts List.**

| CIRCUIT | TRANSISTOR | | DIODES | |
|---|---|---|---|---|
| IF Amplifier | 1st Stage<br>2nd Stage<br>Output | SE5023<br>SE5024<br>T05-0063<br>(S1763) | Video Detector | FD100 |
| Sound IF | Power Detector<br>Amplifier | SE3001<br>uA703 | Ratio Detector | 2X FD100 |
| Audio Amplifier | 1st Stage<br>Output | SE4002<br>SE7020 | | |
| Luminance Amplifier | 1st Video<br>2nd Video<br>Video o/p | SE5025<br>2N3638<br>T0300 | | |
| AGC, Sync, Noise Inverter | AGC Gate<br>AGC Amp - IF<br>AGC Amp - Tuner<br>Noise Inverter<br>Sync Buffer<br>Sync Separator | 2N3638<br>SE6002<br>2N3638<br>SE5025<br>SE5025<br>2N3568 | AGC Gate<br><br>Noise Inverter | FD100<br><br>FD100 |
| Chroma Amplifier, AGC Color Killer, and Burst Amplifier | 1st chroma amp<br>2nd chroma amp<br>3rd chroma amp<br>Burst Amp.<br>ACC Control<br>Killer | SE5023<br>SE5025<br>SE5025<br>SE5025<br>SE4002<br>2N3638 | Burst Detector<br>Gate Pulse Clipper | FD100<br>FD100 |
| Oscillator & Tint | Oscillator<br>Tint Control | uA703<br>SE5025 | | |
| Color Demodulator | Demodulators<br>Low Level<br>Output Stages | <br>6XSE6002<br>3XT0300 | | |

## CONCLUSION

The circuits discussed have been incorporated in a 19-inch color TV receiver demonstrated at the Chicago Spring Conference in June 1966. Performance is almost identical to the equivalent all-tube receiver. The reduction in power and the use of semiconductors should considerably increase system stability and reliability.

These circuits are now approaching an economic and performance standard which make them acceptable to the consumer industry. The ideas presented in this note can be used as a starting point for production designs for hybrid receivers.

## ACKNOWLEDGEMENTS

The author would like to acknowledge the help and advice received from other members of Fairchild's Consumer Applications Group. In particular, I would like to mention Don Smith for his untiring efforts in organizing and constructing the circuits used in the receiver.

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7. Leonard Dietch and August Spencer, "A Pierce Type Injection Locked Oscillator", IEEE Transactions on Broadcast and TV Receivers, Vol. BTR-10, No. 2; July 1964.

## APPENDIX -- Transformer Data

### IF Transformer Data

L1 - 2 turns #26 wire
L2 - 8 turns #32 wire
L3 - 25 turns #32 wire

T1 - 6 1/2 turns #32 wire - Bifilar
T2 - 6 turns #32 wire. Taped at 2 turns.
T3 - 8 turns Primary and Secondary 41.25 MHz trap - 4T.
T4 - 4.5 MHz sound trap.
T5 - Primary 20 turns. Secondary 10 turns. #36 bifilar wire.
T6 - Magnavox Part #361150-1
L1 - L3, T1, T2, T4 and T5 wound on 7/32" diameter coil forms.

### Color Processing Transformer Data

T7 - Primary - 20μh, 45 turns #3/41 litz.
Secondary - 9 turns #3/41 litz.
T8 - 20μh - 45 turns #3/41 litz. Taped at 15 turns 3:1.
T9 - 6μh - Primary and Secondary 24 turns. #3/41 litz. Double tuned.
T10 - 20μh - 45 turns #3/41 litz. Taped at 15 turns 3:1.
T11 - 20μh - Primary and Secondary 45 turns. Secondary overwound on Primary.
T7 through T11 - Wound on a 9/32" diameter coil form.

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